Status of MODIS and VIIRS Instruments

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Acknowledgements:

MODIS Characterization Support Team (MCST)

VIIRS Characterization Support Team (VCST)

Outline

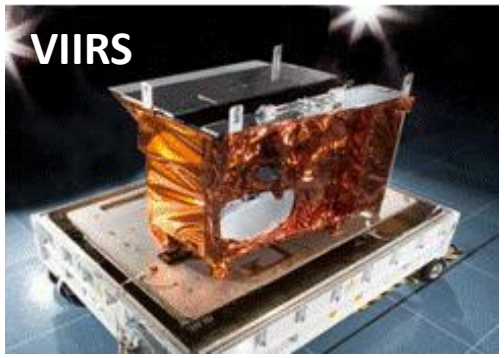
- **Introduction**
  - MODIS and VIIRS Instruments
  - Calibration Approaches
- **MODIS and S-NPP VIIRS On-orbit Performance**
- **MODIS L1B and S-NPP VIIRS SDR (L1B)**
  - Calibration Improvements
- **Summary**

Introduction

- **MODIS on Terra and Aqua Missions**
  - Terra: Dec. 18, 1999 – Present
  - Aqua: May 04, 2002 – Present
- **VIIRS on S-NPP and JPSS Missions**
  - S-NPP: Oct. 28, 2011 – Present
  - JPSS-1 (now NOAA 20): Nov. 18, 2017 – Present
  - JPSS-2: Launch March 2022
  - JPSS-3/4: Launch 2026/2031

Background

- **MODIS**
  - Key instruments for NASA EOS Terra and Aqua
  - Spectral bands: 20 reflective solar bands (RSB) and 16 thermal emissive bands (TEB)
  - Spectral wavelengths: 0.4-14.5 μm
  - Spatial resolutions: 250 m (2 bands), 500 m (5 bands), and 1 km (29 bands)
- **VIIRS**
  - Key instruments for SNPP and JPSS
  - Spectral bands: 14 reflective solar bands (RSB), 7 thermal emissive bands (TEB), and 1 day night band (DNB)
  - Spectral wavelengths: 0.4-12.4 μm
  - Spatial resolutions: 375 m for I bands; 750 m for M bands and DNB



MODIS On-orbit Calibration Methodologies

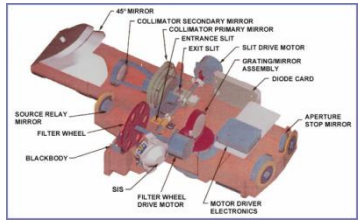
SD/SDSM:
Weekly to tri-weekly

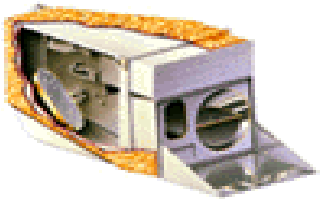
SRCA:
Radiometric: monthly
Spatial: bi-monthly
Spectral: quarterly

Solar Diffuser

SDSM

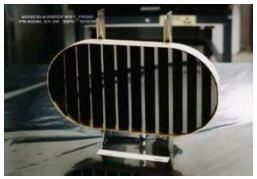
SRCA





Scan Mirror

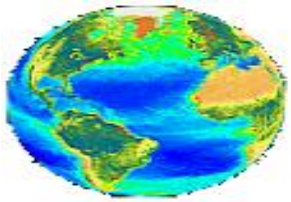
Blackbody



BB: quarterly

Space View

Spacecraft maneuvers:
Yaw (SD BRF, VF)
Roll (Moon)
Pitch (only applied to Terra)

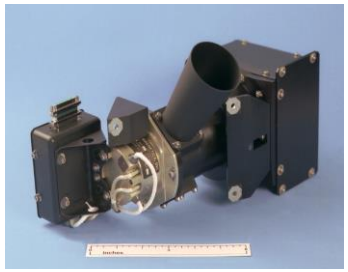


Moon: monthly (nighttime orbits)
0-20° spacecraft roll maneuvers
55° phase angle

Response versus scan-angle (RVS) for MODIS RSB derived using a combination of solar, lunar, and desert response trends

VIIRS On-orbit Calibration Methodologies

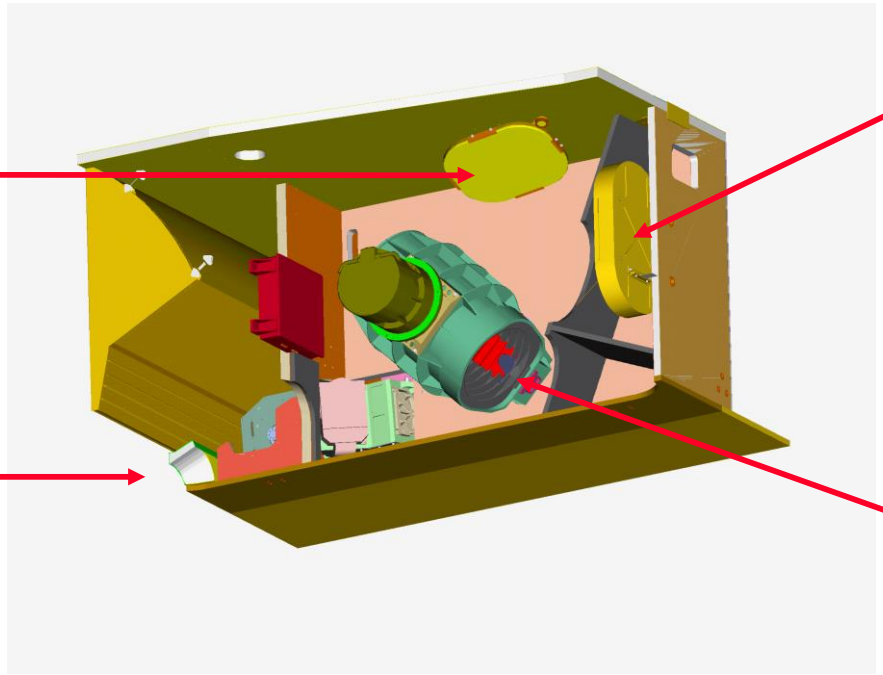
Solar Diffuser Stability Monitor



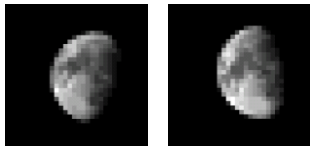
VIIRS on-orbit operation and calibration are based on the experience and lessons from MODIS

Blackbody

Solar Diffuser



Extended SV Port



Rotating Telescope Aft Optics and HAM

Current SDSM operation frequency: N20 (weekly), SNPP (weekly). Reduced from at-launch operation frequency.

MODIS On-orbit Performance

- Terra MODIS
  - Terra MODIS: Stable FPA and Inst. temperatures
  - SD degradation: wavelength-dependent (larger at shorter wavelengths; faster with more solar exposure after the July 2003 SD door anomaly)
  - Terra PV LWIR improvements (electronic crosstalk),restored performance of several noisy detectors
  - Impacts of polarization sensitivity changes for short wavelength bands

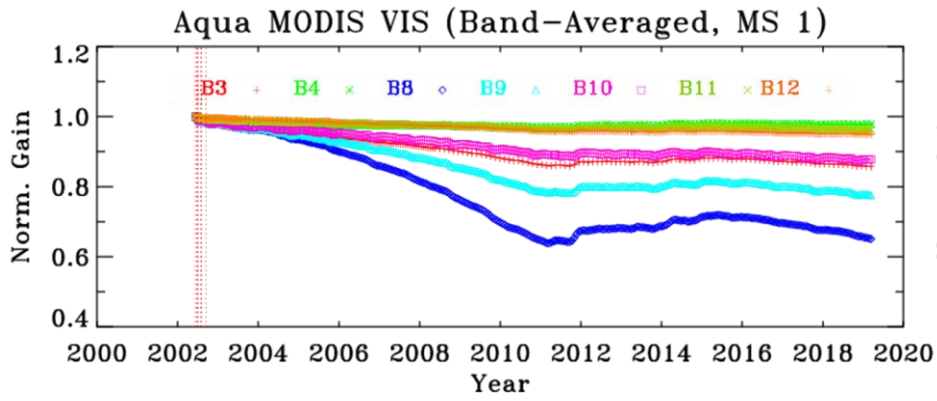
- Aqua MODIS
  - Aqua MODIS: Stable FPA and Inst. temperatures
  - SD degradation: wavelength-dependent but slower than Terra MODIS
  - Improvement in the long-term stability of bands 1-4 (C6.1) after the EV-based RVS corrections

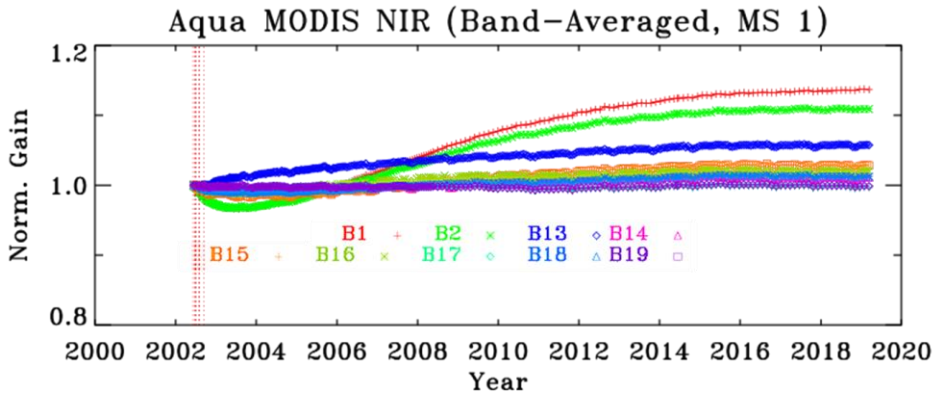
VIIRS On-orbit Performance

- SNPP VIIRS
  - The FPA (VIS/NIR, LWIR): stable, SMIR CFPA temperature increased by 50 mK since launch, BB: very stable
  - SD degradation: wavelength dependent, faster than Aqua MODIS
  - Early mission detector gain decrease in the NIR/SWIR bands has leveled off; TEB gains remain stable
- NOAA-20 VIIRS
  - VIS/NIR FPA temperature stable; CFPA temperature: stable; BB: very stable
  - SD degradation: slightly smaller than S-NPP
  - SNRs exceed requirements except N20 band I3 detector 29 (noisy since prelaunch)
  - RSB detector gains remain stable, TEB gains recovered and remain stable after the mid-mission outgassing
  - DNB stray light correction for both S-NPP and NOAA-20

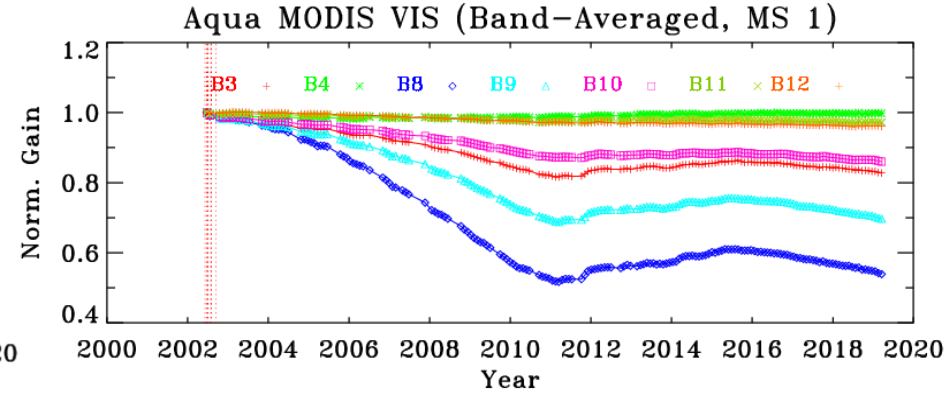
Aqua MODIS VIS/NIR Radiometric Responses

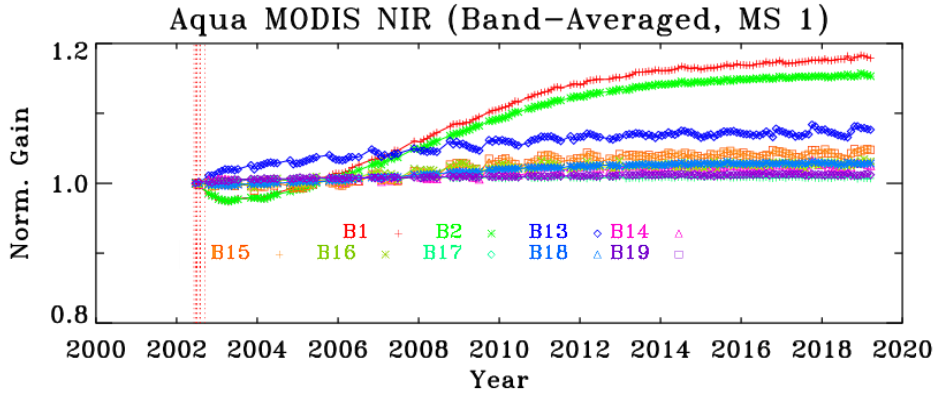
SD View (AOI=50.2°)





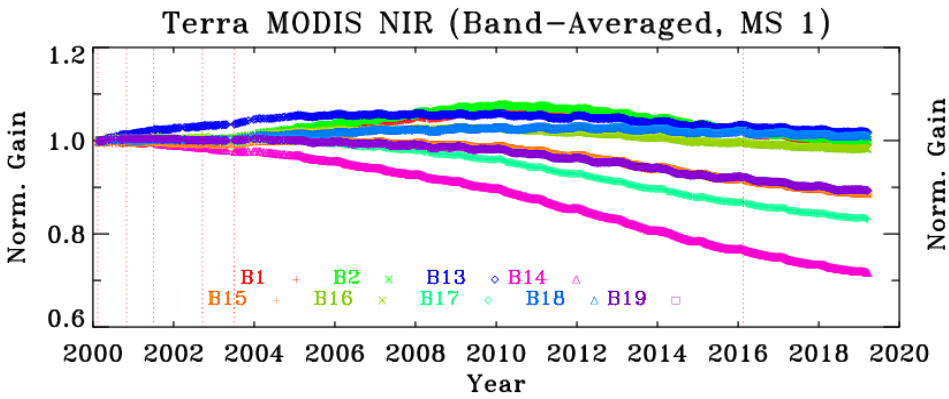
Space View (AOI=11.2°)

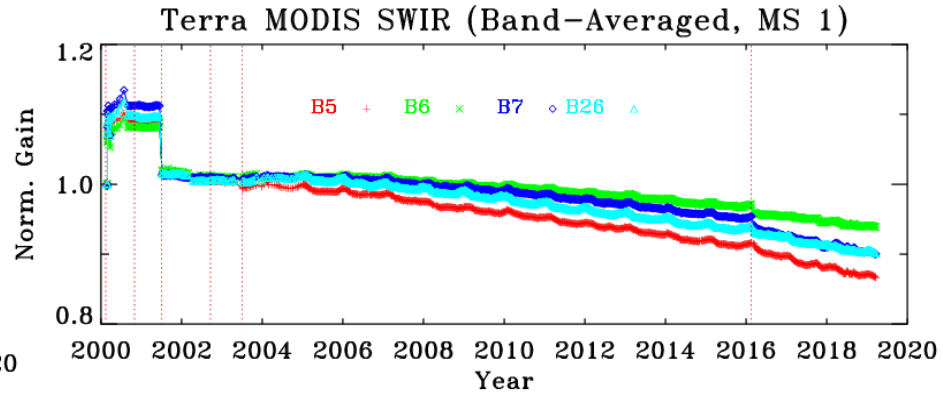


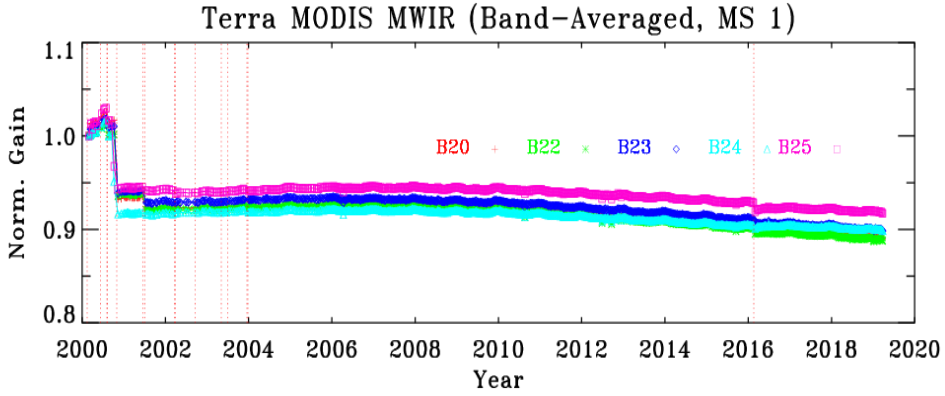


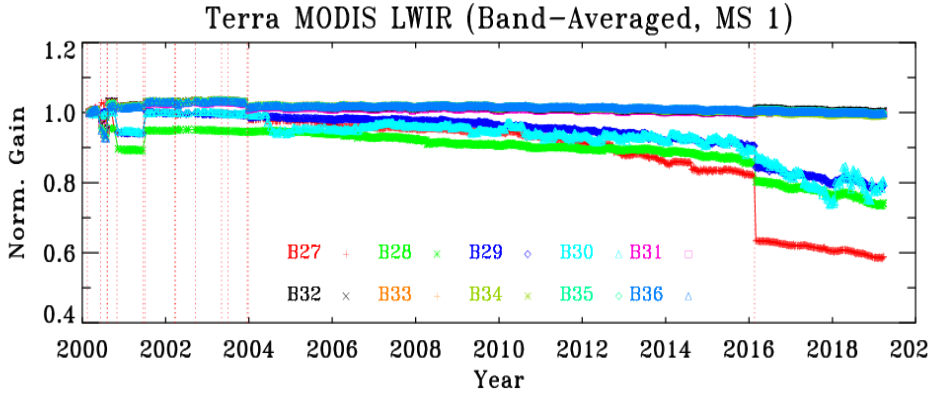
Similar λ, AOI, and mirror side dependence for Terra MODIS VIS and NIR responses

Terra MODIS Radiometric Responses





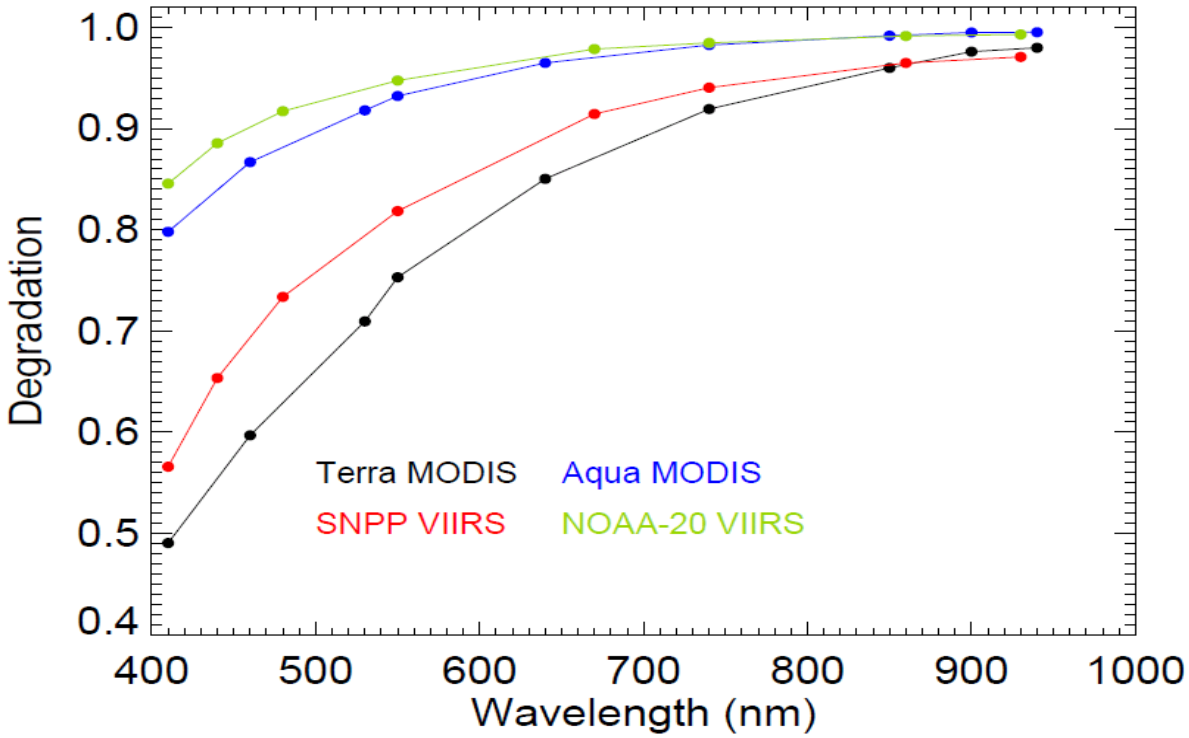




Amplified impacts due to electronic crosstalk in PV LWIR bands after Feb, 2016 safe-hold

MODIS and VIIRS SD Degradation

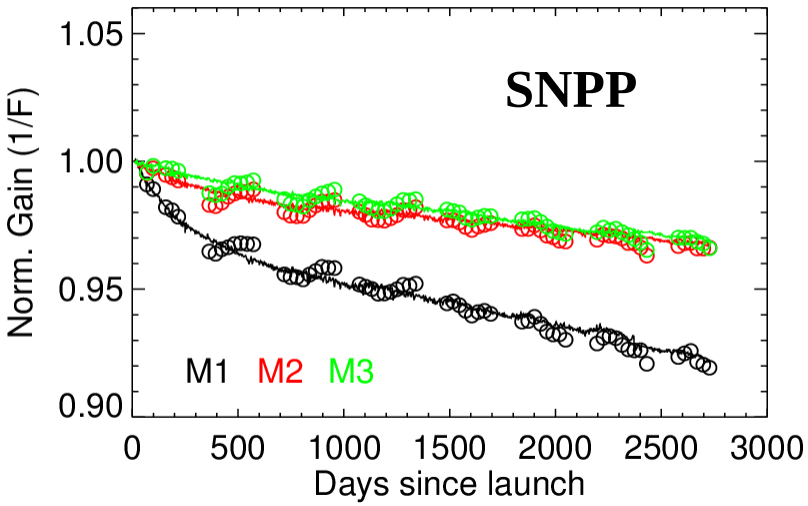
SD degradation monitored by the on-board SDSM

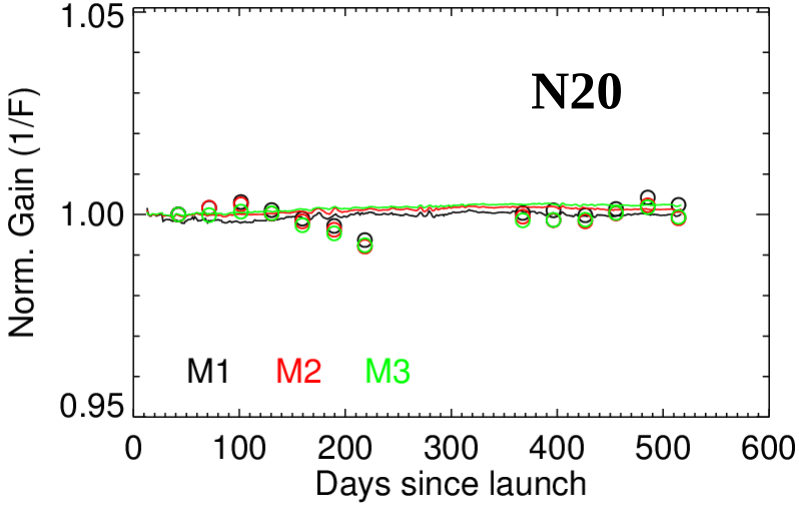


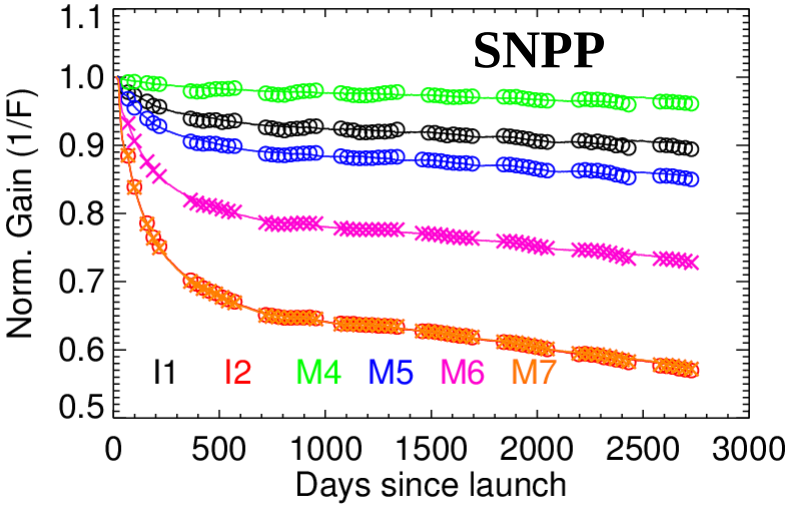
MODIS and VIIRS show similar wavelength dependent SD degradation

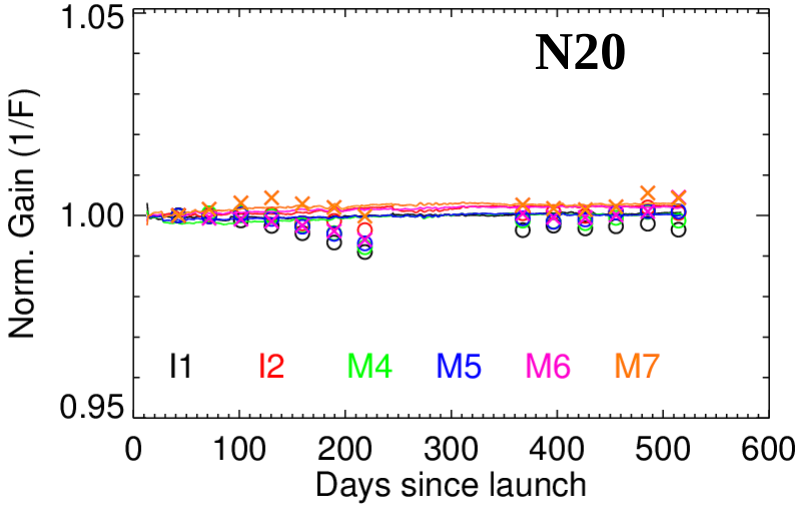
- **Terra MODIS: SD door kept at open since 2003 (1999-present)**
- **Aqua MODIS: SD door opens only during SD/SDM calibration (2002-present)**
- **S-NPP VIIRS: no SD door (2011 to present)**
- **NOAA-20 VIIRS: no SD door (2017 to present)**

VIIRS RSB Spectral Band Responses



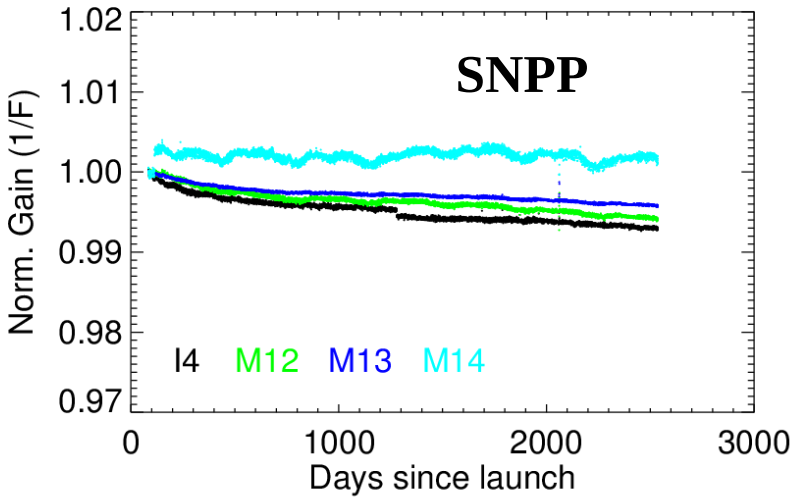


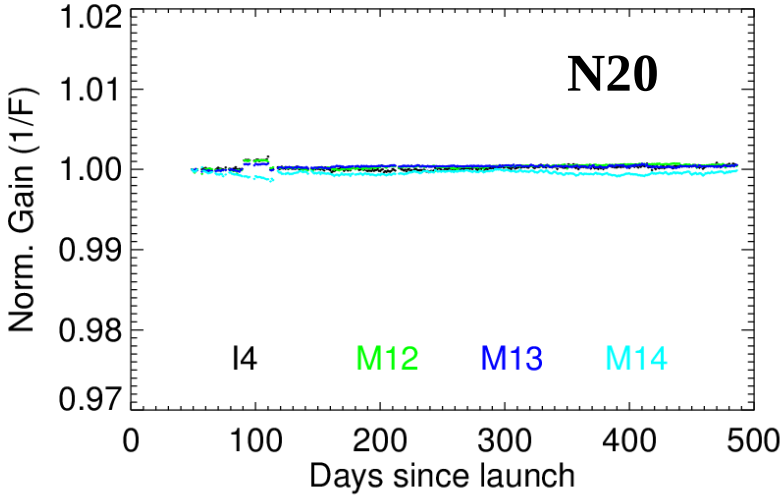


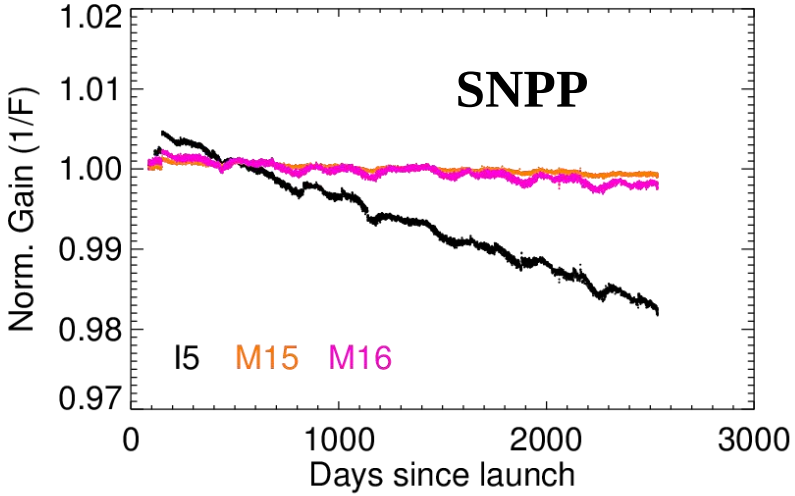


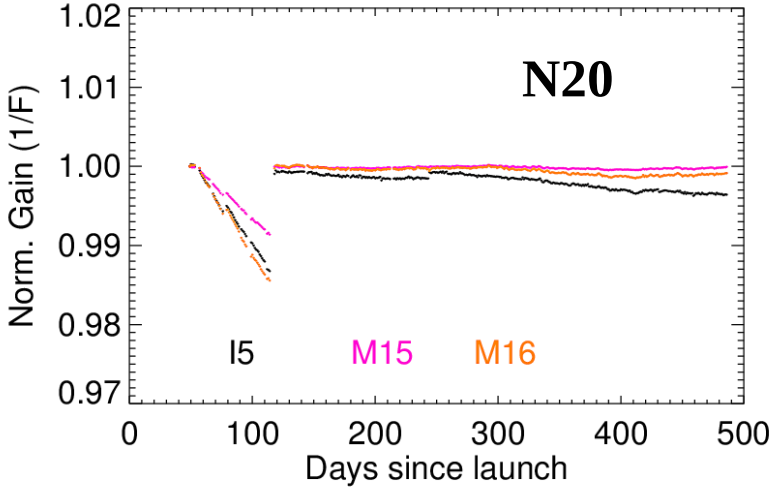
Large changes in SNPP VIIRS NIR/SWIR responses due to telescope mirror degradation ➔ on-orbit modulated RSR

VIIRS TEB Spectral Band Responses (from BB calibration)









Excellent stability for S-NPP VIIRS TEB responses – similar to Aqua MODIS. MODIS has more TEB bands with wavelengths up to 14.5 μm

Status of MODIS Level 1B Data Products (C6 and C6.1)

- **Collection 6 (C6) L1B products released to public July 2012 for Aqua and Nov 2012 for Terra**
- **Collection 6.1 (C6.1) L1B products released to public October 15, 2017**
- **C6 and C6.1 L1B data can be downloaded from:**

  http://ladsweb.nascom.nasa.gov/
- **New improvements in C6.1 release**
  - ***Terra MODIS PV LWIR crosstalk correction applied for bands 27-30***
  - ***Updated QA flagging for several PV LWIR detectors (crosstalk correction restores the performance of detectors)***
  - ***Reprocessed results for Terra MODIS bands 1-2 (2012-2017)***
  - ***Improved response versus scan-angle (RVS) characterization for Aqua MODIS bands 1-4***

Calibration Improvements since the C6.1 release

- **Terra MODIS SWIR band calibration: To mitigate the impact of the electronic crosstalk, a switch in the TEB sending band from 28 to band 25 has been formulated and implemented.**
  - ***Results show improved quality of the calibration coefficients and EV calibrated imagery. The implementation is planned in forward C6.1 and the entire mission reprocess using this approach will be done in a future reprocess***
- **Terra MODIS VIS band polarization impacts**
- **Improved algorithm for Terra and Aqua SWIR SD degradation**

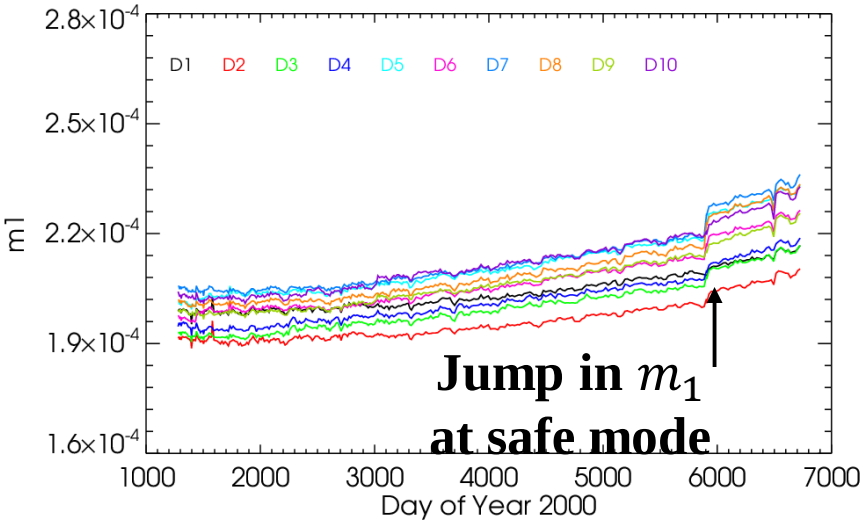
Terra SWIR xtalk improvements

- MODIS SWIR bands (5-7 and 26) have a known issue related to electronic crosstalk and OOB leak identified during prelaunch characterization
  - A correction with its coefficients derived from the night-time-day-mode acquisitions has been applied since early mission. Correction employs band 28 as sending band (Aqua MODIS uses band 25 as sending)
- After the Feb 2016 safe mode, the response of the Terra MODIS PV LWIR bands showed increased impacts due to electronic crosstalk
- Evaluated multiple options to improve mitigation of SWIR xtalk
  - **Use band 25 as sending band in Terra MODIS SWIR correction**

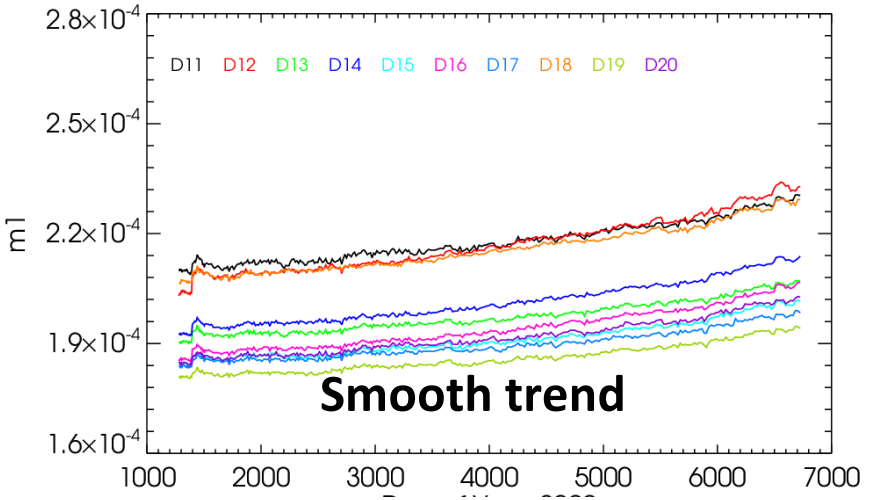
X. Xiong, A. Angal, Y. Li, Proc. SPIE 10781, 1078151 (2018)

Terra SWIR xtalk improvements

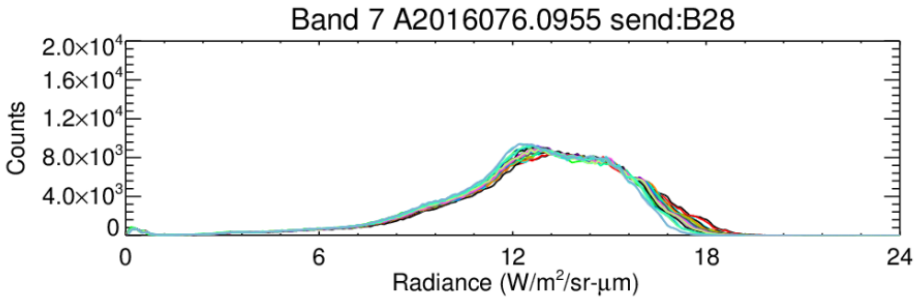
B7 (sf2) m_1 trends with B28 sending

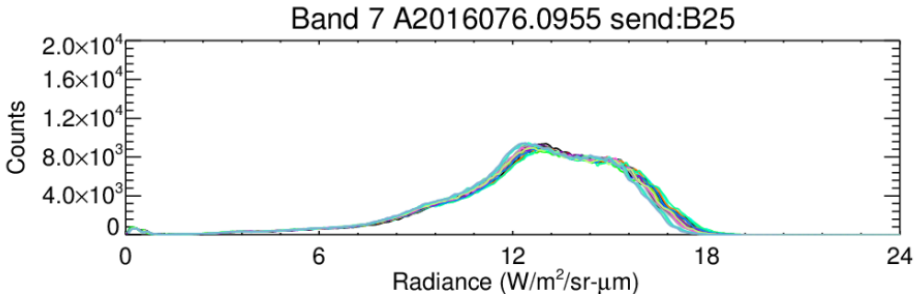


B7 (sf2) m_1 trends with B25 sending



- **Band 7 shows smoother m_1 trends and less detector striping for images after 2016 safe mode**
- **Bands 5 and 6 show similar improvements**





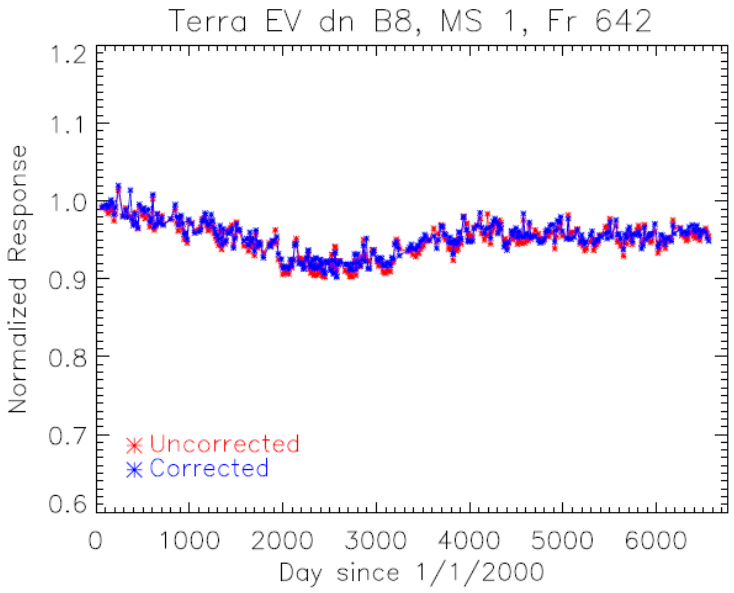
Terra Polarization correction

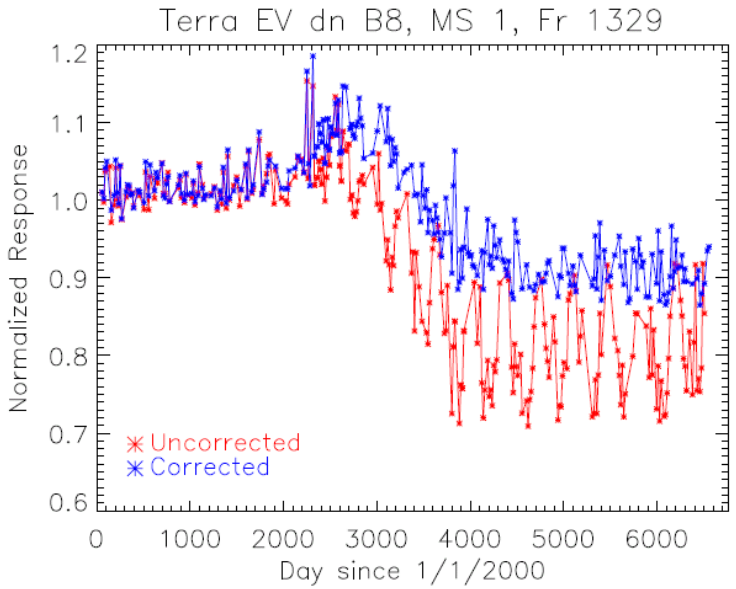
MCST approach for next Collection

Gain (m_1/RVS) derived from desert trends

- Derive BRDF corrected reflectance, ρ_{BRDF}, for desert using first few years of data and the time-dependent OBPG polarization coefficients m_{12} and m_{13}
- Then derive the gain from the measured dn^* and the polarization and BRDF corrected desert reflectance

$$gain = \frac{dn^* \, d_{ES}^2 / \cos(\theta)}{\rho_{BRDF} + m_{12}Q + m_{13}U}$$





Status of S-NPP VIIRS SDR (NASA SIPS Support)

- **Land SIPS SDR reprocess using IDPS Code with VCST LUTs (C1.0 and C1.1)**
  - IDPS SDR/EDR codes Mx based version with LUTs input from VCST.
  - 71 sets of LUTs for RSB (and DNB) have been delivered to Land SIPS for data reprocessing and SDR/EDR assessments in Collections 1.0 and 1.1.

Collection	Code Base	# of LUTs	Period (Year.Month)	Improvements
LPEATE Early	Mx6.3	5	2012.10 - 2013.01	Smoothed functions for SD degradation H-factor and calibration coefficients F-factor.
	Mx6.4	5	2013.04 - 2013.11	Updated SD/SDSM screen transmission, SD BRDF, RTA mirrors degradation model, and modulated RSRs.
LPEATE C1	Mx7.2	25	2013.12 - 2016.02	Improved time-dependent modulated RSR, DNB stray light correction, H & F fitting functions. (LSIPS data AS3110)
LSIPS C1	Mx8.11	36	2016.03 - 2019.05	Improved Quality Flags, intruduced DNB gain ratio and LGS LUTs, fixed solar/lunar vectors, with RSBAutoCal option. (LSIPS data AS5000)

- **Atmosphere SIPS SDR reprocess using IDPS Code with VCST LUTs**
  - Mission data reprocessing VIIRS SDR/EDR using Mx8.4 software in late 2014.
  - 9 sets of LUTs based on Mx8.4 code format have been delivered (Nov 2014 - Feb 2016) – same quality as those sent to Land C1.1.

Status of S-NPP VIIRS L1B (NASA SIPS Support)

- **NASA SIPS L1B Software**
  - VIIRS L1A and L1B software/LUT and data design are developed under NASA EDOS/SIPS.
  - VIIRS L0 data as the input for L1A software => 6-min L1A data.
  - L1A and L1B calibration LUTs are the input for L1B software => Geolocation and L1B products including OBC. Calibrated data files are reduced from 22,000 SDRs to 720 L1Bs daily.
  - First L1B software V1.1.0 was released in Jan 2016 for SIPS evaluation and testing.
  - V2.0.0 was officially released in Oct 2016.
  - V3.0.0 was officially released in August 2018 for both S-NPP and NOAA-20 (JPSS-1).
  - LUTs generations are based on corrected solar vector (error fix), on-orbit SD/SDSM screen transmission & SD BRDF, modulated RSR, and consistent fitting of mission data.
  - Data can be downloaded from :**http://ladsweb.nascom.nasa.gov/**

Collection	Code Base	# of LUTs	Period (Year.Month)	Improvements
LSIPS Testing	L1B V1.1.0	20	2016.02 - 2017.09	Redesigned L1B software, LUTs, and data format using L1A data input.
LSIPS C1	L1B V2.0.0	31	2016.08 - 2019.05	Improved L1B software functions and algorithms. (LSIPS data AS5110)
LSIPS Evaluation	L1B V3.0.0	14	2018.01 - 2019.05	Run for both NPP and J1. Add different RTA encoder start value for J1. Modify J1 DNB GEO over extended mode. Introduce M11 process at Ops_Night. Improve M13 radiometric resolution. Add moon phase and illumination for DNB pixel.
LSIPS C2	L1B V3.0.x	-	Summer 2019	Mission LUTs for reprocessing. Add noisy detector quality flags.

Status of N20 VIIRS L1B (NASA SIPS Support)

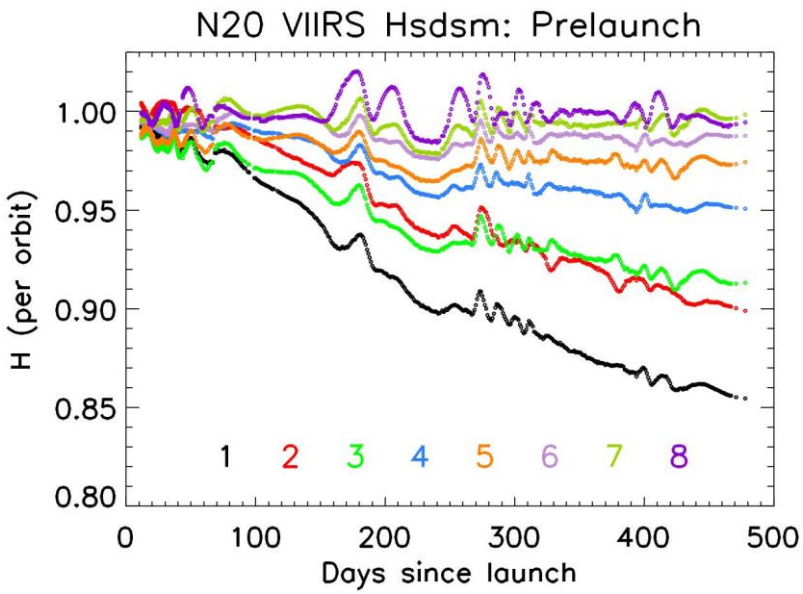
- **NASA SIPS L1B for NOAA-20 (JPSS1)**
  - L1B software V3.0.0-rc (release candidate versions 1-6) were released between Dec 2017 and July 2018 for SIPS evaluation and testing by using N20 pre-launch LUTs.
  - V3.0.0 was released in August 2018 with full NOAA-20 (JPSS1) and S-NPP support.
  - V3.0.0 LUTs updates have been released by VCST with 2 months forward prediction.
  - Land SIPS plans to reprocess N20 mission using V3.0.0 software in May 2019.
  - The improvements in the N20 LUTs include on-orbit SD/SDSM screen transmission & SD BRDF and consistent fitting of mission data.

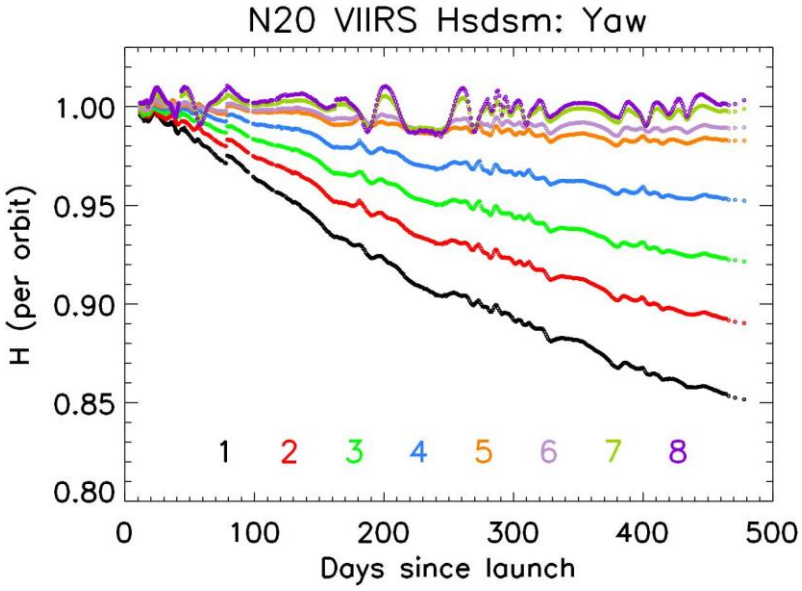
Collection	Code Base	# of LUTs	Period (Year.Month)	Improvements
LSIPS Evaluation	L1B V3.0.0	6	2018.06 - 2019.04	Run for both NPP and J1. Add different RTA encoder start value for J1. Modify J1 DNB GEO over extended mode. Introduce M11 process at Ops_Night. Improve M13 radiometric resolution. Add moon phase and illumination for DNB pixel. (LSIP data AS3194)
LSIPS C2	L1B V3.0.x	-	Spring 2019	Mission LUTs for reprocessing. Add noisy detector quality flags.

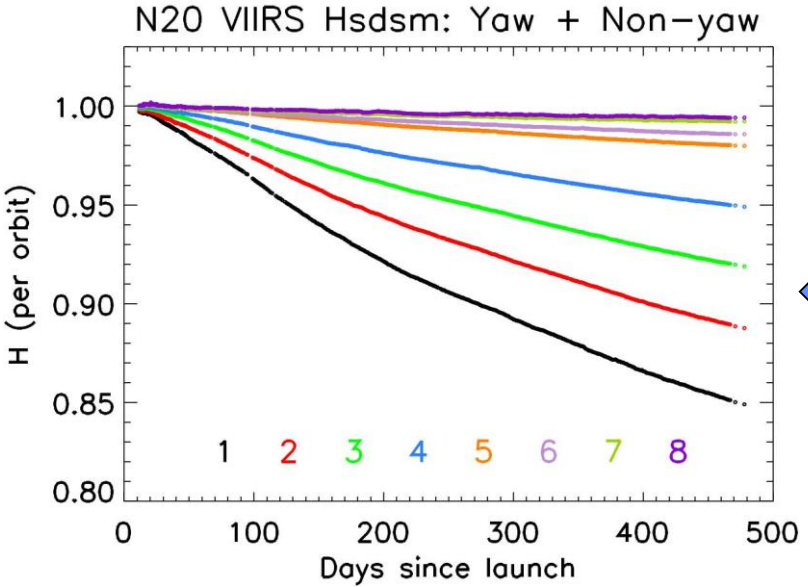
S-NPP VIIRS L1B RSB Calibration for Collection 2

- **NASA SIPS L1B for NOAA-20 (JPSS1)**
  - Use the correct Delta-C table consistent in F-Predicted LUT and in L1B software. Use a fixed c0=0. Impact as up to 0.5%. Largest in bands I1, I2, M4 and M5. No impact on M1, M2, M8-M11.
  - Solar Diffuser (SD) degradation H-factors are adjusted by solar azimuth angular dependence for all Reflective Solar Bands (RSB) with impact up to 0.25%. The SD positional dependence is also applied to H-factor to reduce Earth View striping, with impact by up to 0.8%.
  - Apply 6 years lunar calibration data to adjust H-factor RTA view, with impact as large as 0.5% in band M1.
  - Noisy detector quality flags are included in L1B.
  - Uncertainly index to be applied in L1B.

N20 VIIRS Screen Characterization Improvements







<u>Collection 2 Improvement</u>

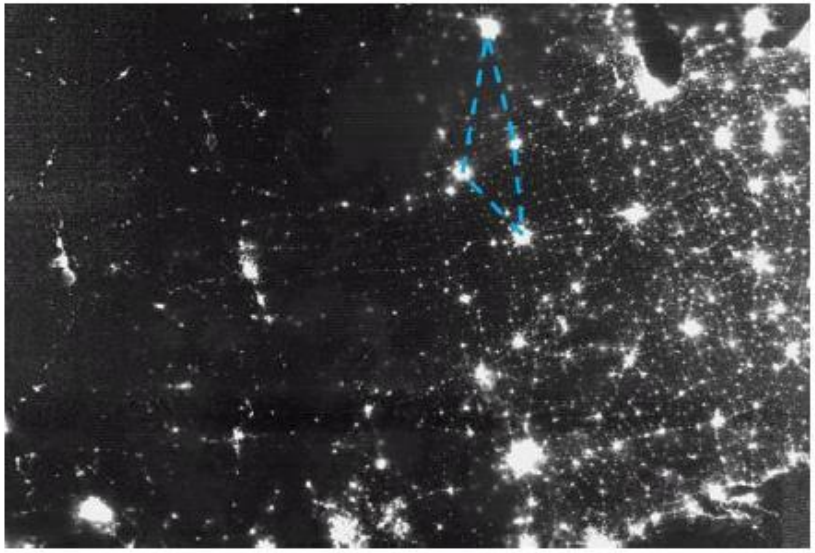
SDSM screen BRDF*tau supplementing the yaw measurements with on-orbit measurements to achieve a better characterization

DNB Stray Light Correction

S-NPP: 08:35:00, 07/13/18 (N. America)

N-20: 07:44:45, 07/13/18 (N. America)

S-NPP: 08:35:00, 07/13/18 (N. America)



N-20: 07:44:45, 07/13/18 (N. America)

Summary

- Both Terra (19 years) and Aqua (17 years) MODIS and their OBC continue to operate and function normally
- Both S-NPP (~8 years) and NOAA-20 (~1.5 years) VIIRS and their OBC continue to operate and function normally
- Efforts by MCST and VCST, including support from SDST, SIPS, and science algorithm developers, remain critical to ensure and improve sensor calibration and data quality
- Challenging issues identified for both MODIS and VIIRS will be investigated and addressed for future calibration improvements in support of their data processing/reprocessing
- More efforts are needed to better understand the calibration differences among sensors and to help generate consistent data products of high quality

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Backup Slides

Key Design Requirements of MODIS Spectral Bands

Primary Use	Band	Bandwidth (nm)	Spectral Radiance[1]	Required SNR
Land/Cloud/Aerosols Boundaries	1	620 - 670	21.8	128
	2	841 - 876	24.7	201
Land/Cloud/Aerosols Properties	3	459 - 479	35.3	243
	4	545 - 565	29	228
	5	1230 - 1250	5.4	74
	6	1628 - 1652	7.3	275
	7	2105 - 2155	1	110
Ocean Color/ Phytoplankton/ Biogeochemistry	8	405 - 420	44.9	880
	9	438 - 448	41.9	838
	10	483 - 493	32.1	802
	11	526 - 536	27.9	754
	12	546 - 556	21	750
	13	662 - 672	9.5	910
	14	673 - 683	8.7	1087
	15	743 - 753	10.2	586
	16	862 - 877	6.2	516
Atmospheric Water Vapor	17	890 - 920	10	167
	18	931 - 941	3.6	57
	19	915 - 965	15	250
Surface/Cloud Temperature	20	3.660 - 3.840	0.45 (300K)	0.05
	21	3.929 - 3.989	2.38 (335K)	0.2
	22	3.929 - 3.989	0.67 (300K)	0.07
	23	4.020 - 4.080	0.79 (300K)	0.07
Atmospheric Temperature	24	4.433 - 4.498	0.17 (250K)	0.25
	25	4.482 - 4.549	0.59 (275K)	0.25
Cirrus Clouds Water Vapor	26	1.360 - 1.390	6	150 (SNR)
	27	6.535 - 6.895	1.16 (240K)	0.25
	28	7.175 - 7.475	2.18 (250K)	0.25
Cloud Properties	29	8.400 - 8.700	9.58 (300K)	0.05
Ozone	30	9.580 - 9.880	3.69 (250K)	0.25
Surface/Cloud Temperature	31	10.780 - 11.280	9.55 (300K)	0.05
	32	11.770 - 12.270	8.94 (300K)	0.05
Cloud Top Altitude	33	13.185 - 13.485	4.52 (260K)	0.25
	34	13.485 - 13.785	3.76 (250K)	0.25
	35	13.785 - 14.085	3.11 (240K)	0.25
	36	14.085 - 14.385	2.08 (220K)	0.35

[1] Spectral Radiance values are (W/m^2-μm-sr)

20 reflective solar bands (RSB) and 16 thermal emissive bands (TEB)

VIIRS (and MODIS) Spectral Bands

16 Moderate (radiometric) bands, 5 Imaging bands, 1 DNB

VIIRS Band	Spectral Range (um)	Nadir HSR (m)	MODIS Band(s)	Range	HSR
DNB	0.500 - 0.900				
M1	0.402 - 0.422	750	8	0.405 - 0.420	1000
M2	0.436 - 0.454	750	9	0.438 - 0.448	1000
M3	0.478 - 0.498	750	3 10	0.459 - 0.479 0.483 - 0.493	500 1000
M4	0.545 - 0.565	750	4 or 12	0.545 - 0.565 0.546 - 0.556	500 1000
I1	0.600 - 0.680	375	1	0.620 - 0.670	250
M5	0.662 - 0.682	750	13 or 14	0.662 - 0.672 0.673 - 0.683	1000 1000
M6	0.739 - 0.754	750	15	0.743 - 0.753	1000
I2	0.846 - 0.885	375	2	0.841 - 0.876	250
M7	0.846 - 0.885	750	16 or 2	0.862 - 0.877 0.841 - 0.876	1000 250
M8	1.230 - 1.250	750	5	SAME	500
M9	1.371 - 1.386	750	26	1.360 - 1.390	1000
I3	1.580 - 1.640	375	6	1.628 - 1.652	500
M10	1.580 - 1.640	750	6	1.628 - 1.652	500
M11	2.225 - 2.275	750	7	2.105 - 2.155	500
I4	3.550 - 3.930	375	20	3.660 - 3.840	1000
M12	3.660 - 3.840	750	20	SAME	1000
M13	3.973 - 4.128	750	21 or 22	3.929 - 3.989 3.929 - 3.989	1000 1000
M14	8.400 - 8.700	750	29	SAME	1000
M15	10.263 - 11.263	750	31	10.780 - 11.280	1000
I5	10.500 - 12.400	375	31 or 32	10.780 - 11.280 11.770 - 12.270	1000 1000
M16	11.538 - 12.488	750	32	11.770 - 12.270	1000

1 DNB:
L/M/HG
32 Agg. Modes

14 RSB:
0.41-2.3 μm

7 DGB:
M1-M5, M7, and M13

7 TEB:
3.7-12.1 μm